engineering laboratory

Enabling the Digital Thread for Smart Manufacturing

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Systems Integration Division

NIST
National Institute of Standards and Technology
U.S. Department of Commerce

Projects

- Measuring the PMI Model Capability in CAD Systems
- STEP File Analyzer
- Testing the Digital Thread
- Design to Manufacturing and Inspection (D2MI)
- Validation of Downstream CAM and CMM Processes

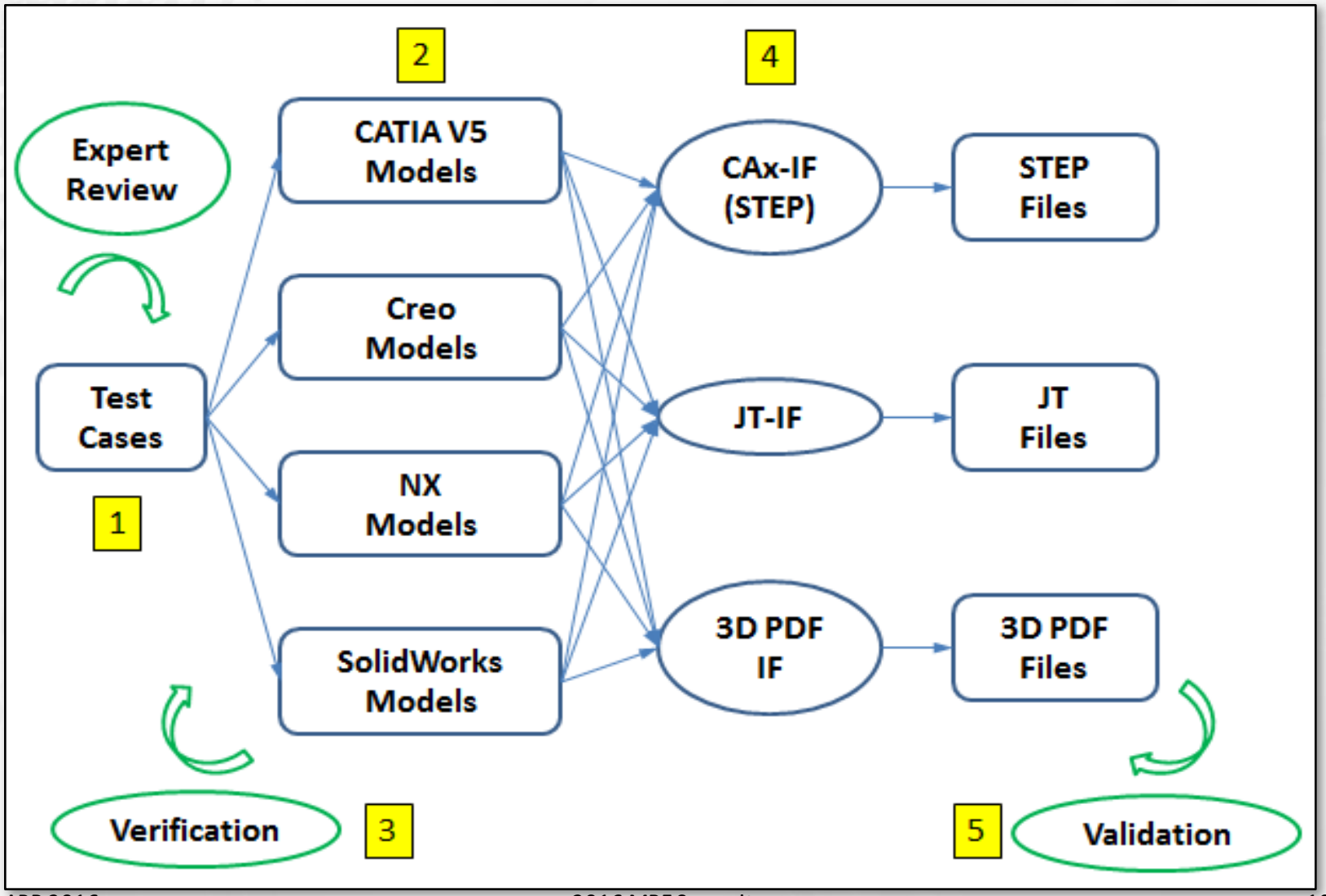
Free Stuff !

- 13 test case definitions
- 38 CAD models
- 28 STEP files
- 8 papers and reports
- 3 videos
- 2 trade journal articles
- 1 software program
- **Stay tuned for the URL**

Measuring the PMI Modeling Capability in CAD Systems

- Measure the conformance of CAD software and derivative files to ASME tolerance standards
- 11 test case definitions based on Y14.5 and Y14.41, approximately 100 PMI annotations
- 8 test cases modeled in 4 CAD systems
- Verification of CAD models to test cases
- Derivative STEP, JT, and 3D PDF files
- Validation of derivative files to CAD models
- 3 reports on verification and validation

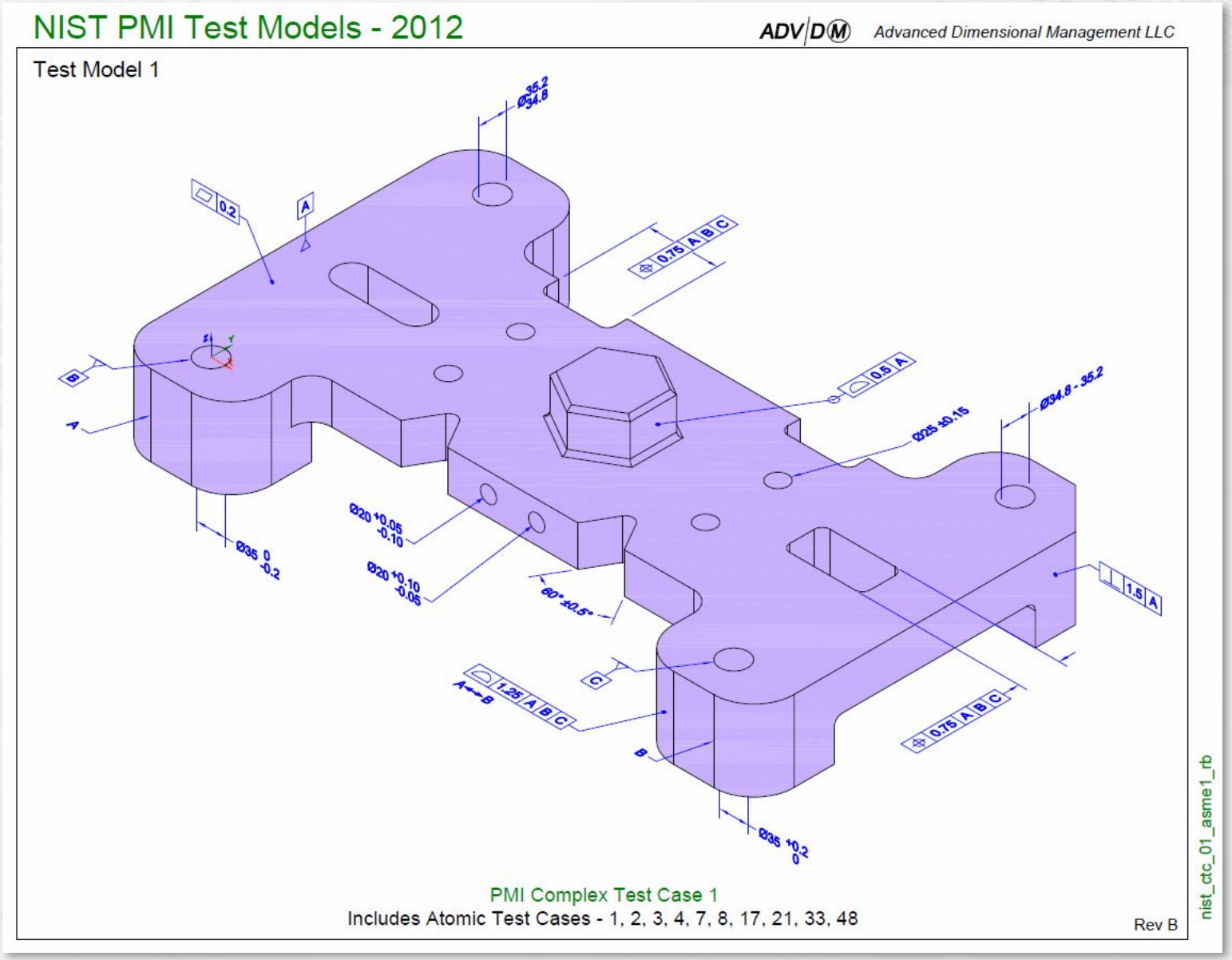
Measuring the PMI Modeling Capability in CAD Systems



Two Types of Test Cases

- Combined Test Case
  - Not a complete specification of PMI
- Fully-toleranced Test Case
  - Each feature is adequately controlled and constrained
- Both types contain geometric and dimensional tolerances, datums, and modifiers
- Not necessarily best practice or how you might tolerance a part

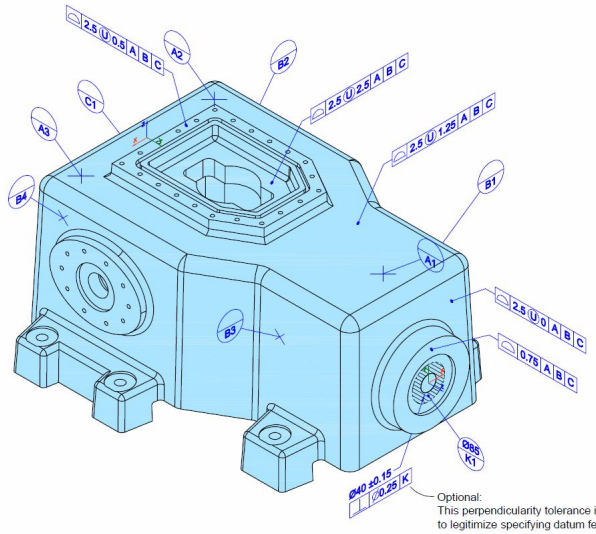
Combined Test Case



NIST PMI Test Models - 2012

ADV|D(M) Advanced Dimensional Management LLC

Test Model 2



PMI Complex Test Case 2 - View 2 (of 3)
Includes Atomic Test Cases - 26, 31, 41

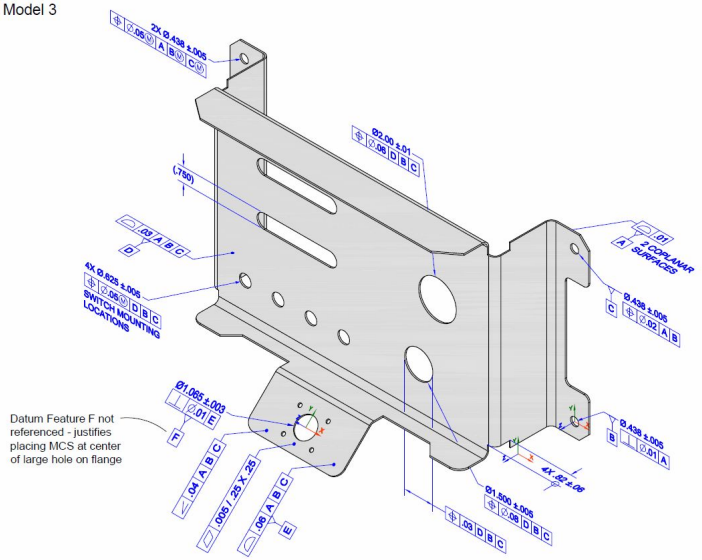
Rev B

nist_ctc_02_asme1_rb

NIST PMI Test Models - 2012

ADV|D(M) Advanced Dimensional Management LLC

Test Model 3



PMI Complex Test Case 3
Includes Atomic Test Cases - 6, 13, 14, 20, 27, 32, 36, 39, 45, 46

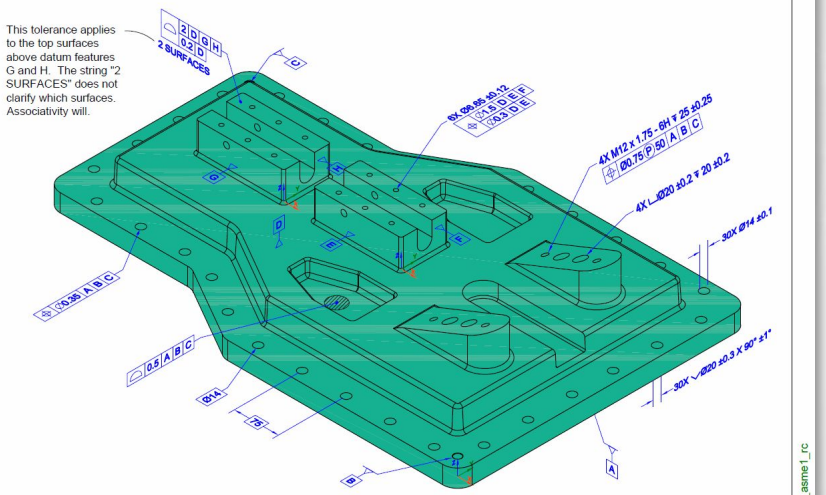
Rev B

nist_ctc_03_asme1_rb

NIST PMI Test Models - 2012

ADV|D(M) Advanced Dimensional Management LLC

Test Model 4



PMI Complex Test Case 4
Includes Atomic Test Cases - 5, 9, 10, 12, 15, 16, 22, 30, 40, 49

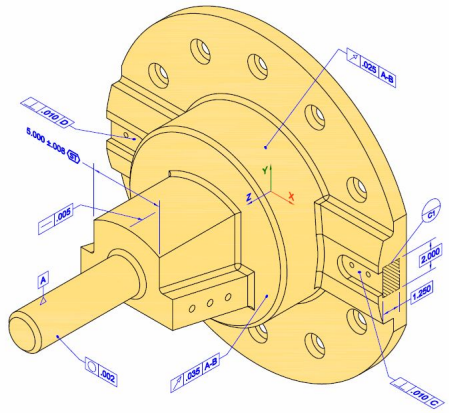
Rev C

nist_ctc_04_asme1_rc

NIST PMI Test Models - 2012

ADV|D(M) Advanced Dimensional Management LLC

Test Model 5

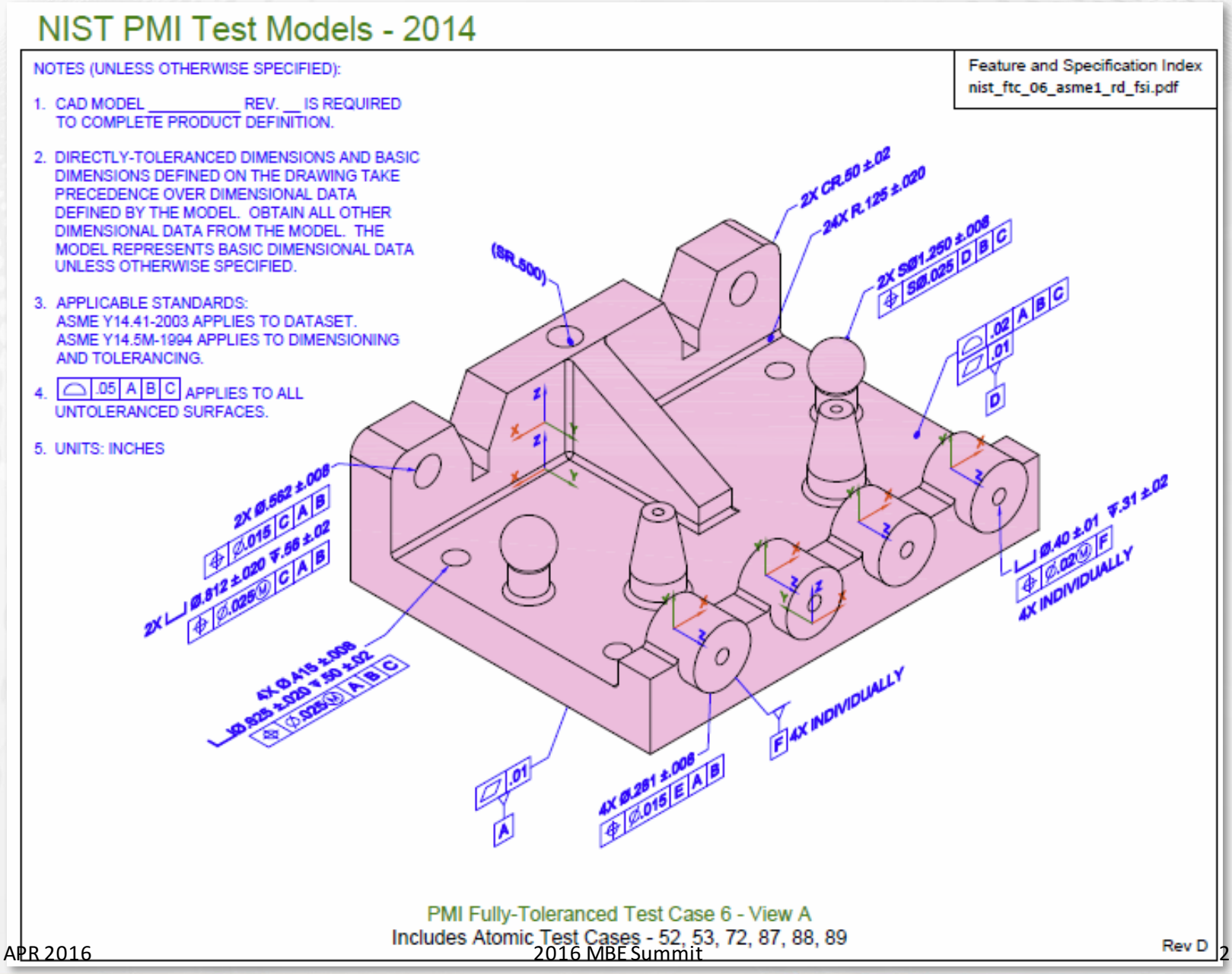


PMI Complex Test Case 5 - View 1 (of 2)
Includes Atomic Test Cases - 11, 18, 19, 24, 37, 42, 44

Rev C

nist_ctc_05_asme1_rc

Fully-toleranced Test Case



NIST PMI Test Models - 2014

NOTES (UNLESS OTHERWISE SPECIFIED):

1. CAD MODEL _____ REV. __ IS REQUIRED TO COMPLETE PRODUCT DEFINITION.
2. DIRECTLY-TOLERANCED DIMENSIONS AND BASIC DIMENSIONS DEFINED ON THE DRAWING TAKE PRECEDENCE OVER DIMENSIONAL DATA DEFINED BY THE MODEL. OBTAIN ALL OTHER DIMENSIONAL DATA FROM THE MODEL. THE MODEL REPRESENTS BASIC DIMENSIONAL DATA UNLESS OTHERWISE SPECIFIED.
3. APPLICABLE STANDARDS:
   ASME Y14.41-2003 APPLIES TO DATASET.
   ASME Y14.5M-1994 APPLIES TO DIMENSIONING AND TOLERANCING.
4. .06 A B C APPLIES TO ALL UNTOLERANCED SURFACES.
5. DIMENSIONING AND TOLERANCING APPLY WITH PART RESTRAINED AS FOLLOWS, EXCEPT AS INDICATED.

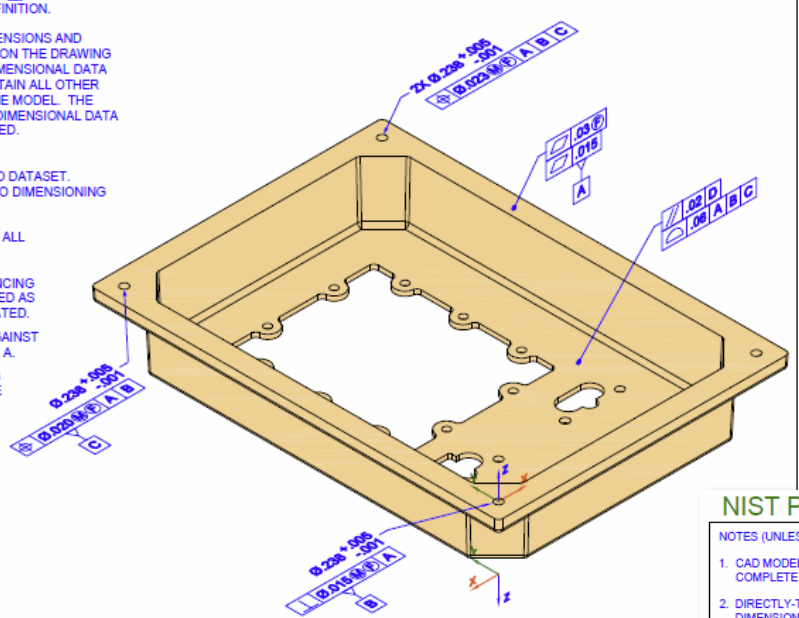
   PLACE DATUM FEATURE A AGAINST DATUM FEATURE SIMULATOR A.

   ENGAGE DATUM FEATURES B AND C WITH DATUM FEATURE SIMULATORS B AND C RESPECTIVELY.

   APPLY LOAD TO PART TO RESTRAIN DATUM FEATURE A AGAINST ITS SIMULATOR.

   DETAILED INSPECTION PLAN NEEDED TO COMPLETELY DEFINE RESTRAINT.
6. UNITS: INCHES

Feature and Specification Index
nist_ftc_08_asme1_rc_fsi.pdf



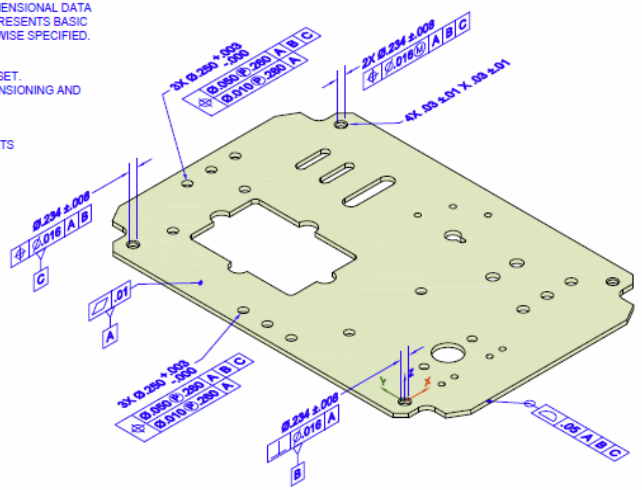
PMI Fully-Toleranced Test Case 8 - View A
Includes Atomic Test Cases - 66, 90

NIST PMI Test Models - 2014

NOTES (UNLESS OTHERWISE SPECIFIED):

1. CAD MODEL _____ REV. __ IS REQUIRED TO COMPLETE PRODUCT DEFINITION.
2. DIRECTLY-TOLERANCED DIMENSIONS AND BASIC DIMENSIONS DEFINED ON THE DRAWING TAKE PRECEDENCE OVER DIMENSIONAL DATA DEFINED BY THE MODEL. OBTAIN ALL OTHER DIMENSIONAL DATA FROM THE MODEL. THE MODEL REPRESENTS BASIC DIMENSIONAL DATA UNLESS OTHERWISE SPECIFIED.
3. APPLICABLE STANDARDS:
   ASME Y14.41-2003 APPLIES TO DATASET.
   ASME Y14.5M-1994 APPLIES TO DIMENSIONING AND TOLERANCING.
4. DIMENSION AND TOLERANCE VALUES SHOWN IN SQUARE BRACKETS [XXX] ARE MILLIMETERS.
5. MATERIAL: (.1196 THICK) 11 GA 304 SST SHT, ASTM A240.
6. UNITS: INCHES

Feature and Specification Index
nist_ftc_09_asme1_rd_fsi.pdf



PMI Fully-Toleranced Test Case 9 - View A
Includes Atomic Test Cases - 59, 61

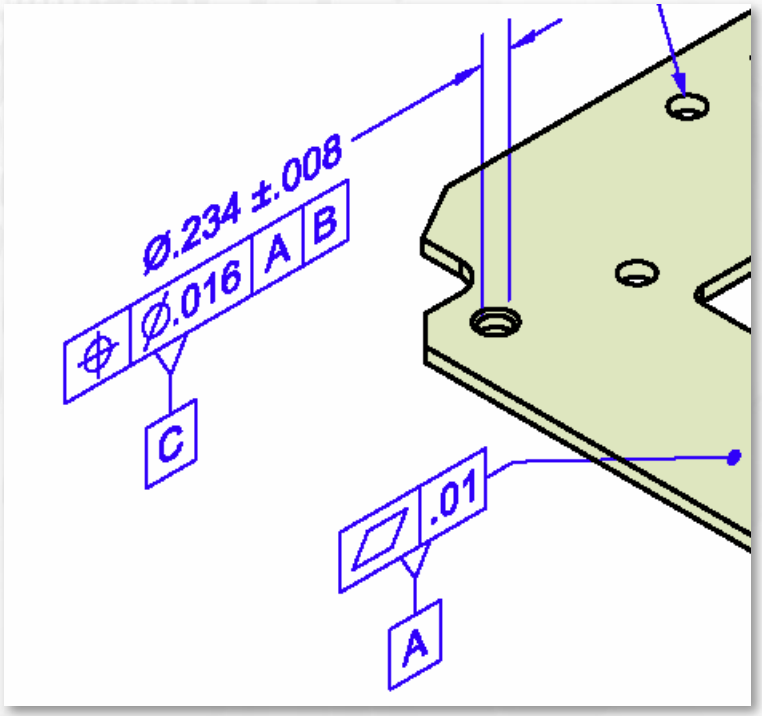
Rev D

Measuring the PMI Modeling Capability in CAD Systems

- Verification of CAD models and validation of derivative files based on many characteristics of PMI representation and presentation
- Report generic results from the CAD systems
- End-user testing
  - MBE workflows
  - CAM and inspection software
  - STEP file import

STEP File Analyzer

- Generates spreadsheets from STEP files
- Visual analysis of PMI representation



Test Case

CAD Model

STEP File

STEP File Analyzer

▱ | .01 ▽ | [A]	
Ø.234 ± .008 ⌖ | Ø .016 | A | B ▽ | [C]	

STEP File Analyzer

- Automated checking of coverage of PMI elements
- Color-coded by expected number of PMI elements in the NIST test cases

- Column A – PMI elements (tolerances, dimensions, datums, modifiers)
- Column B – Number of PMI elements

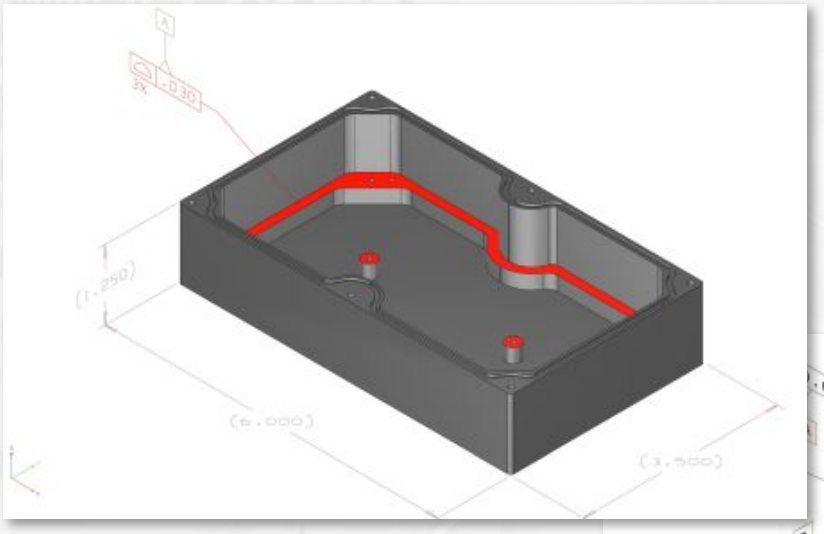
	A	B
1	nist_ctc_03_asme1_ap242.stp	
2		
3	**PMI Element**	**Count**
4	angularity_tolerance ∠	1
5	circular_runout_tolerance ↗	
6	coaxiality_tolerance ◎	
7	concentricity_tolerance ◎	
8	cylindricity_tolerance ⌭	
9	flatness_tolerance ⏥	1
10	line_profile_tolerance ⌒	
11	parallelism_tolerance //	
12	perpendicularity_tolerance ⊥	2
13	position_tolerance ⌖	6
14	roundness_tolerance ○	
15	straightness_tolerance -	
16	surface_profile_tolerance ⌓	3
17	symmetry_tolerance ⌯	
18	total_runout_tolerance ⌰	
19	composite tolerance (6.9.9)	
20	dimensional location (5.1.1)	2
21	dimensional size (5.1.5)	8/7
22	diameter Ø	8/7
23	radius R	
24	spherical SØ	
25	spherical radius SR	
26	thickness ⏤⏤	
27	angular location (5.1.2)	
28	angular size (5.1.6)	
29	basic dimension (5.3)	
30	reference dimension (5.3)	0/1
31	plusminus - equal (5.2.3)	8
32	plusminus - unequal (5.2.3)	

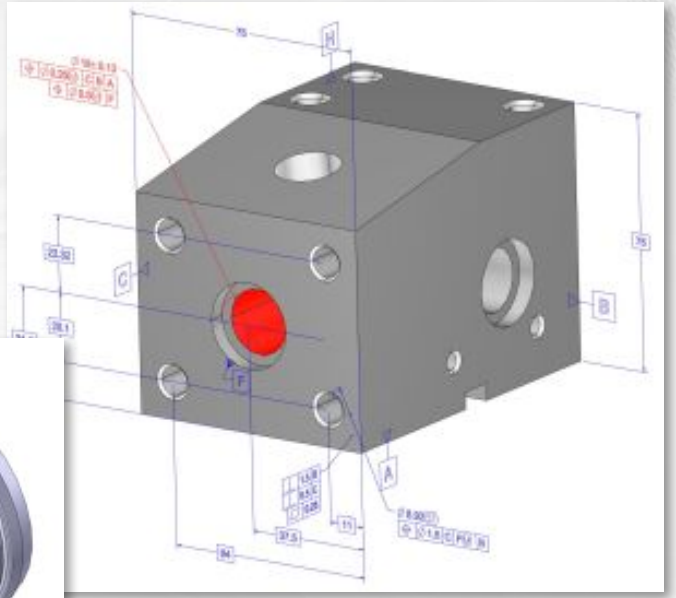
Coverage for Multiple STEP files

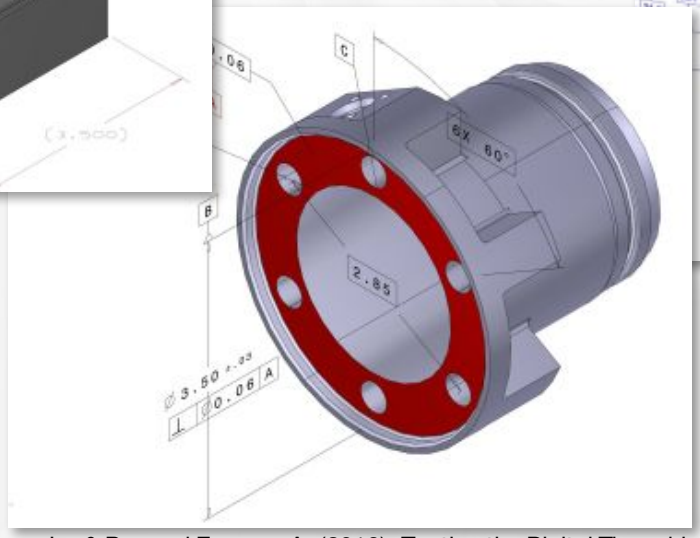
	PMI Element	sp5	sp5	sp5	sp5	sp5	sp5	sp5	sp5	sp5	sp5	sp5	sp5	sp5	sp5	sp5	sp5
4	angularity_tolerance ∠																
5	circular_runout_tolerance ↗									1							
6	coaxiality_tolerance ◎																
7	concentricity_tolerance ◎																
8	cylindricity_tolerance ⌭								2								
9	flatness_tolerance ▱	3	3	1	3	1	2/3	1	1	1	1/3	2/3	1	3	3	1	1	3
10	line_profile_tolerance ⌒																	
11	parallelism_tolerance //		5			1	5					4/5			5			
12	perpendicularity_tolerance ⊥	2	1	4	2	1	1	3/4	5		1/2	0/1	0/4	2	1	4	4	2
13	position_tolerance ⌖	11	13	23	9/11	10	13	16/23	17/19		0/11	0/13	1/23	11	13	23	23	11
14	roundness_tolerance ○									1								
15	straightness_tolerance -								0/1									
16	surface_profile_tolerance ⌓	11	11	3	7/11	11	6/11	1/3	9	0/1	7/11	7/11	3	11	11	3	3	11
17	symmetry_tolerance ÷								1									
18	total_runout_tolerance ⌰																	
19	composite tolerance (6.9.9)	4	6	2	2/4	6	7/6	2	3		2/4	1/6	0/2	4	6	2	2	4
20	dimensional location (5.1.1)	10	1	16/8	2/10	0/5	1	1/8	2	1	10	1	13/8	10	1	5/8	16/8	10
21	dimensional size (5.1.5)	14	9	11/14	11/14	10/11	9	16/14	15/16	4/5	13/14	9	14	14	9	22/14	11/14	14
22	diameter Ø	10	9	11/14	8/10	9/11	9	14	13/16	2	10	9	14	11/10	9	14	11/14	11/10
23	radius R	2/1		0/2	3/1	1		2	2	2	3/1		0/2	3/1		0/2	0/2	3/1
24	spherical SØ	0/1			0/1						0/1			0/1				0/1
25	spherical radius SR	1			0/1						0/1			0/1				0/1
26	thickness ⟊⟊																	
27	angular location (5.1.2)																	
28	angular size (5.1.6)																	
29	basic dimension (5.3)																	
30	reference dimension (5.3)	0/5	0/1		1/5		0/1			0/1	2/5	1		5	1			0/5
31	plusminus - equal (5.2.3)	19		19	12/19	1/7		13/19	12/18	4	21/19		25/19	19		19	19	19
32	plusminus - unequal (5.2.3)		0/9	0/2		8	9	2				9	2		9	2	2	
33	value range (5.2.4)					1												
34	type qualifier (5.2.2)								2	1/3								
35	tolerance class (5.2.5)								3									
36	oriented dimensional location (5.1.3)				1/0													
37	derived shapes dimensional location (5.1.4)																	
38	location with path (5.1.7)																	
39	decimal places (5.4)				13	12	10	17	17	5	23	10	27				27	24
40	datum (6.5)	10	11	8	5/10	5	9/11	8	9/11	2	10	11	11/8	10	11	8	8	10
41	point datum target (6.6)	6/0									6/0			6/0				
42	line datum target (6.6)																	0/0

Testing the Digital Thread

- Compare manufacturing and inspection of a part via 2D drawing process versus 3D model process



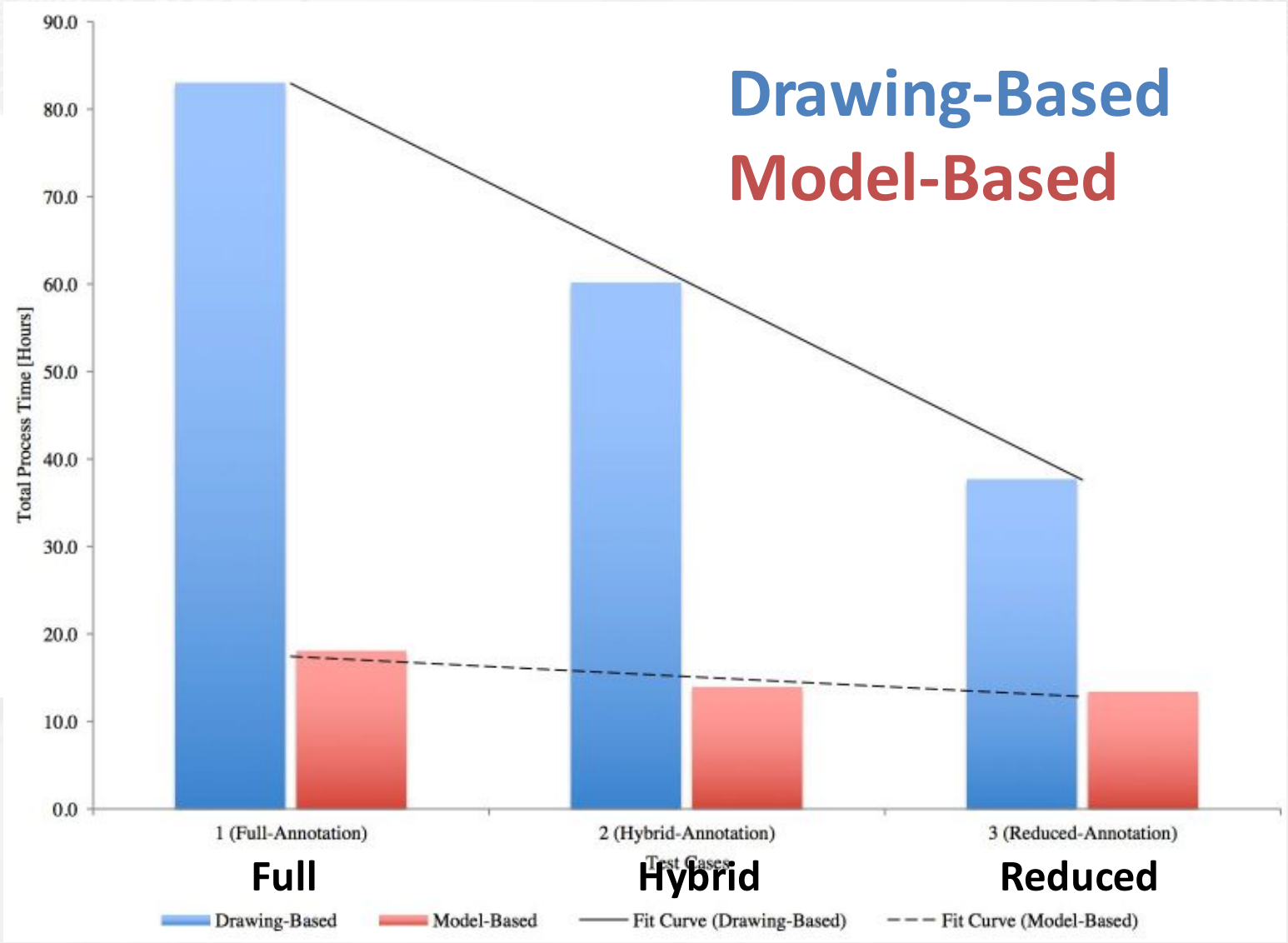




Hedberg Jr, T. D., Lubell, J., Fischer, L., Maggiano, L., & Barnard Feeney, A. (2016). Testing the Digital Thread in Support of Model-Based Manufacturing and Inspection. *Journal of Computing and Information Science in Engineering, 16*(2), 1-10. doi:10.1115/1.4032697

Testing the Digital Thread

Total Process Time



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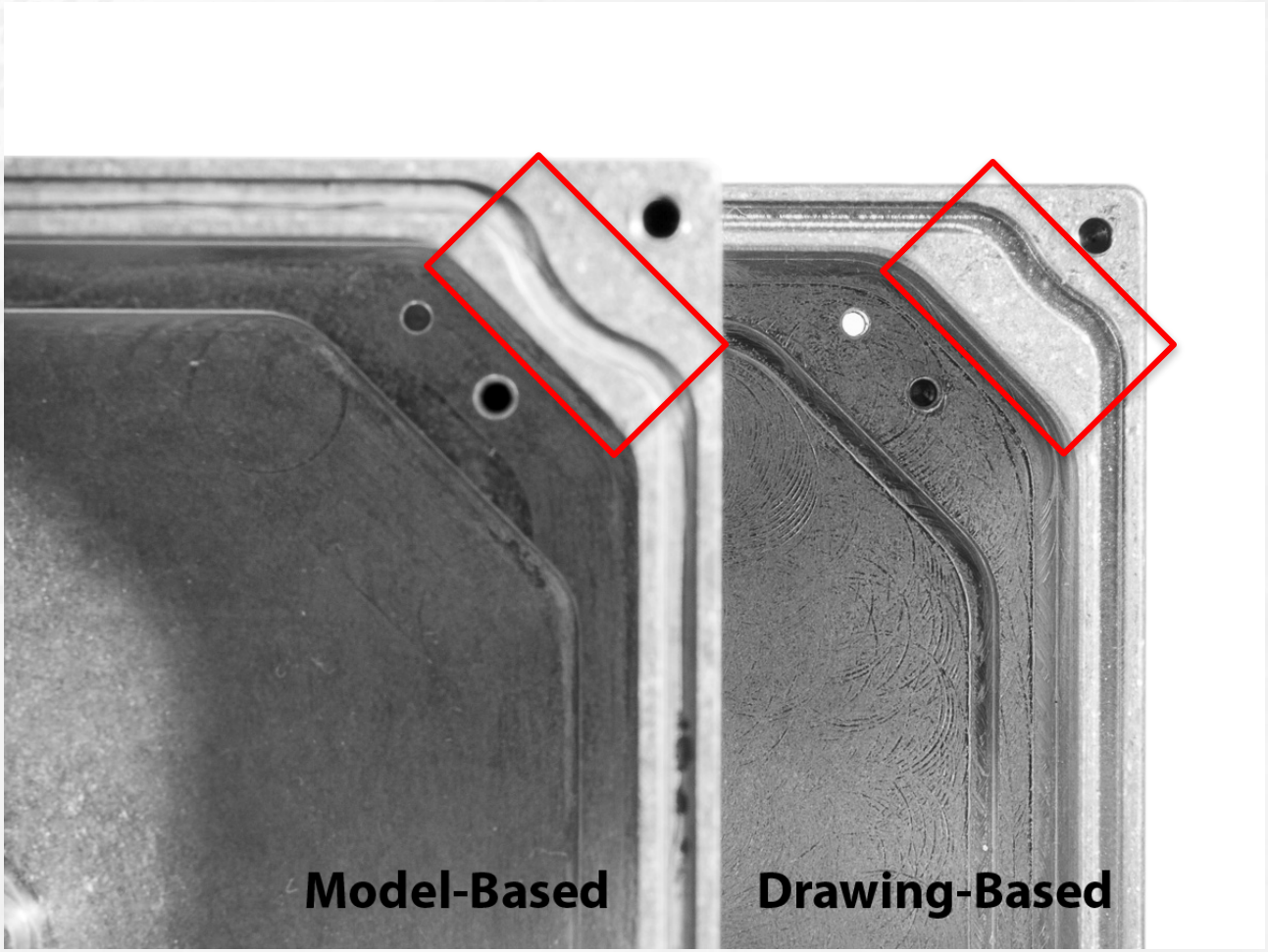
Testing the Digital Thread



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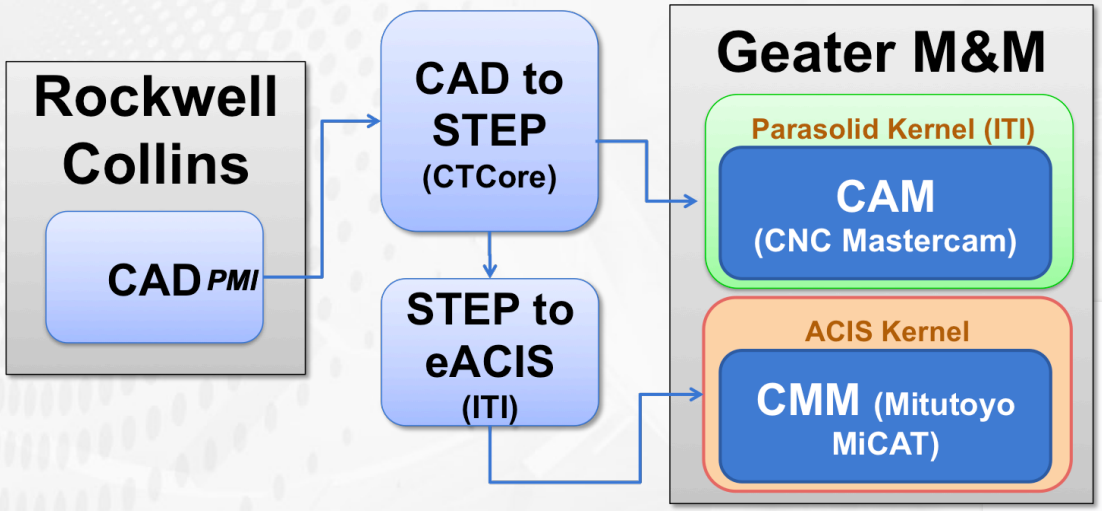
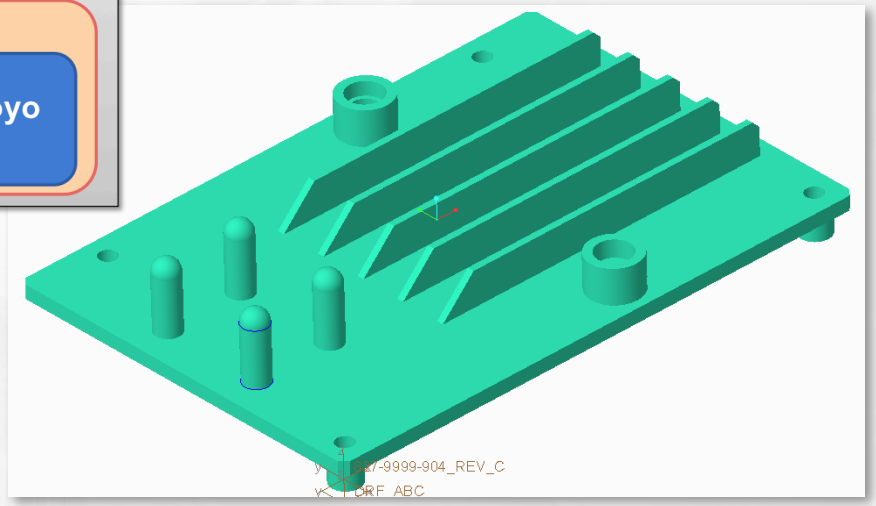
Design to Manufacturing and Inspection (D2MI)

- Demonstrate the value of model-centric CAD-to-CAM and CAD-to-CMM data interoperability using STEP AP242 with embedded PMI
  - Reduce or eliminate recreation of part design data
  - Reduce cycle time, cost, and risk of downstream errors
  - Increase part yield and quality
- CAD PMI to STEP to CAM
- CAD PMI to STEP to ACIS to CMM

Design to Manufacturing and Inspection (D2MI)





- Identified gaps between STEP and ACIS for PMI
- Compared modeling time between 2D drawing and 3D modeling process

Validation for Downstream CAM and CMM Processes

- Validation of ACIS models used for downstream CAM and CMM processes in D2MI project
- Analysis of STEP AP242 and Quality Information Framework (QIF)

Free Stuff !

- **http://go.usa.gov/6nPh**
- 13 test case definitions
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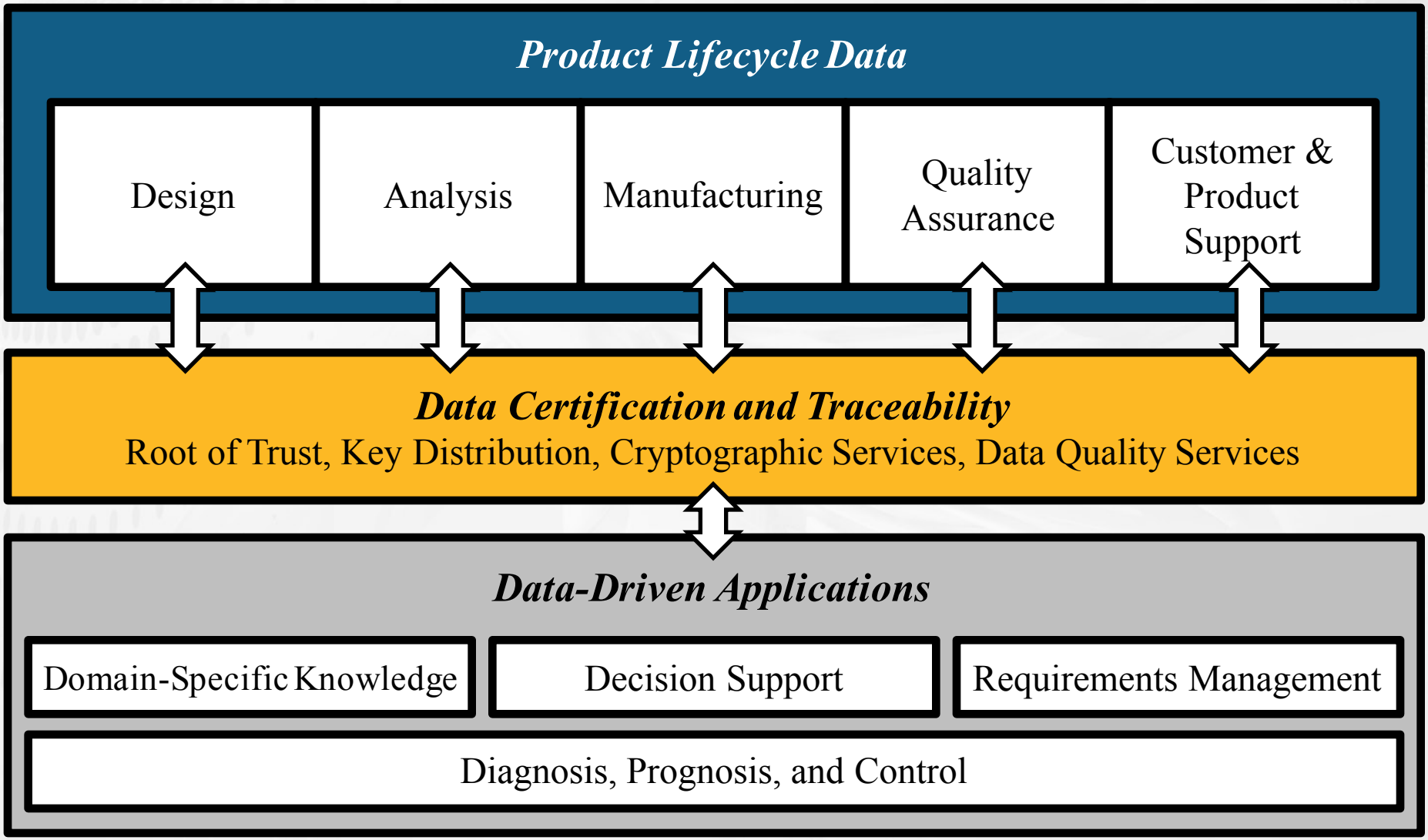
- 3 videos
- 2 trade journal articles
- 1 software program

Check back for more updates!

Lifecycle Information Framework



engineering laboratory

Modeling Methodology for Smart Manufacturing

Peter Denno

Systems Integration Division

NIST
National Institute of Standards and Technology
U.S. Department of Commerce